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COMMITTEE ON SPACE RESEARCH

IRI CCBW 2025
29 September – 10 October 2025
Trieste, Italy

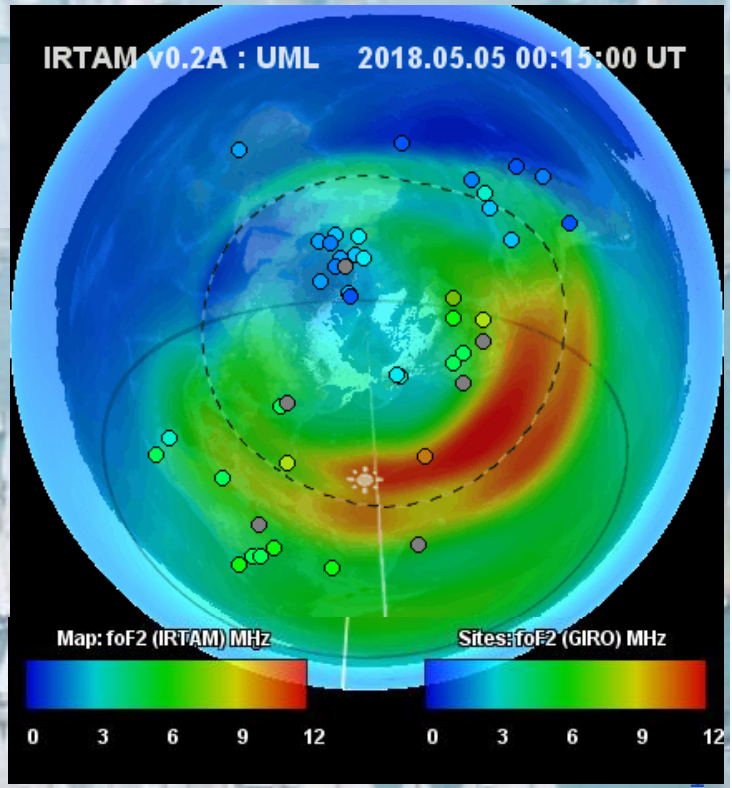
IRTAM

a Real-Time Assimilative IRI

REALISTIC RION IONOSPHERE

GAMBIT SITUATION ROOM

Presented by Ivan Galkin
University of Massachusetts Lowell, USA



IRI Capacity Building Workshop 2025

Trieste, Italy • 30 September 2025

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Outline

- **Galloping Introduction to IRTAM**
  - **IRTAM**
    - NECTAR "model-morphing" method (not a Kalman filter)
      - Anomaly maps for a physics-informed assimilation
      - "Significantly 4DDA": 24-hour of previous data at each update step
        - » Diurnal harmonics as "eigen functions" of
      - Attenuation trajectories for spatial prediction
  - **GAMBIT**
    - GAMBIT Explorer software
    - GAMBIT Situation Room for real-time monitoring
    - MUF(3000) weather maps for PECASUS/ICAO
    - Data fusion with GNSS VTEC
      - Weather maps of plasma slab thickness
  - **Path forward**
    - Assimilation of data from moving platforms
    - D-region specification using ionosondes

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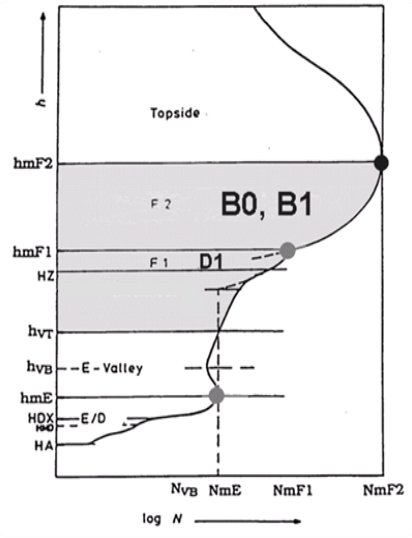
Real-Time IRI

- **Real-Time IRI Task Force**
  - concept: tweak IRI using available observations
    - To make a good model better
      - Ja Soon S. (CCMC) and GEM Challenge
    - Not necessarily an assimilation
      - Example of assimilative IRI: adjusting ISSN driver (IG12)
    - "Real-time IRI" refers to application to space weather
- **IRTAM is IRI-based Real-Time Assimilative Model**
  - 3D weather density model based on four 2D maps
    - NmF2, hmF2, B0 and B1
    - Captures [most of] the ionospheric dynamics
      - Smoothing
        - » Max resolution: 4-hour order harmonic as in IRI
      - Es, D-region, and disturbance level are not included
  - Current IRTAM version 0.4A
    - Assimilates real-time data from GIRO ionosondes
    - Path forward: add assimilation of the Radio Occultation profiles



The vertical profile of plasma density:

16 "anchor" parameters

B0 and B1: profile shape is important!

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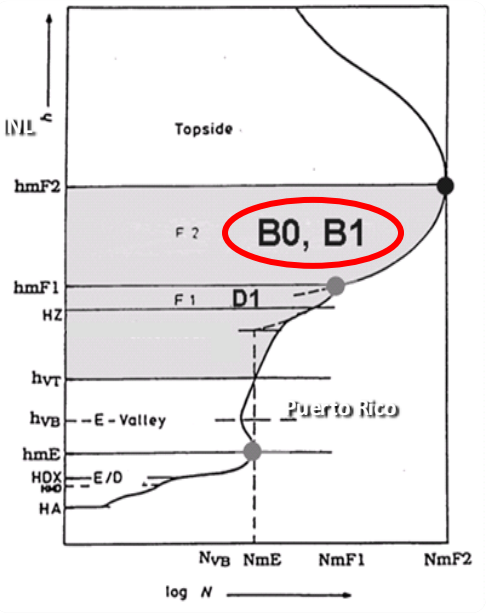

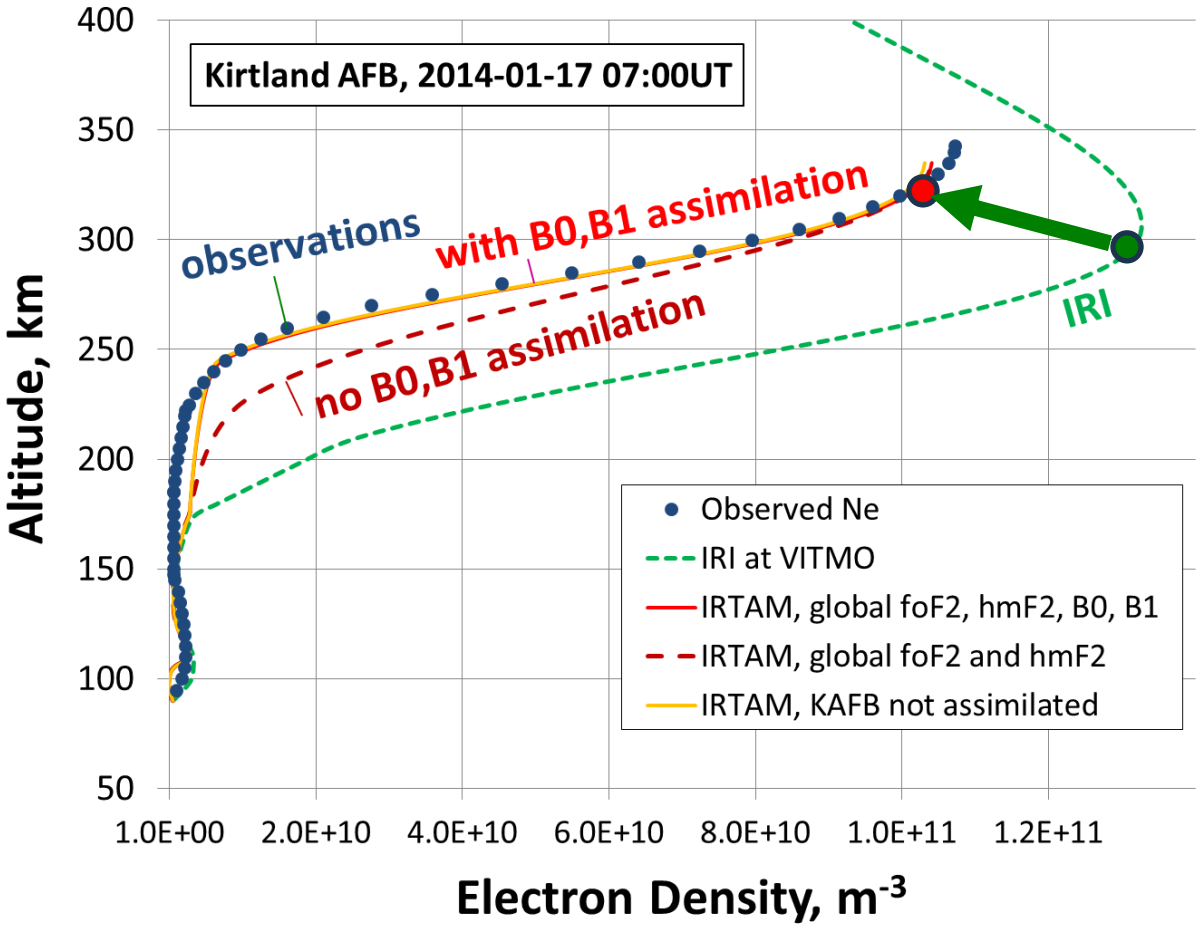

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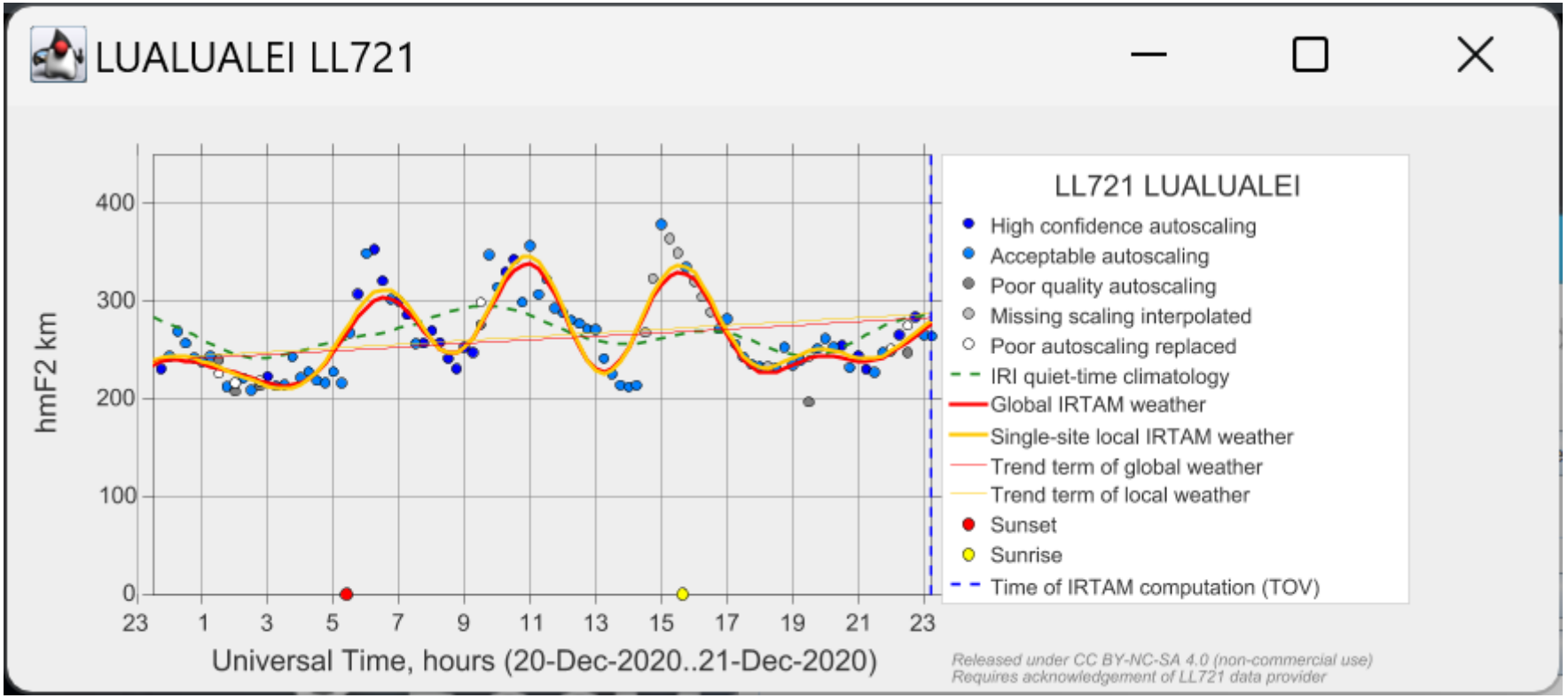
Single station chart of IRI, ionosonde, and IRTAM

One IRTAM Computation = Red Line, matches 24 hours of data

Available online at https://giro.uml.edu



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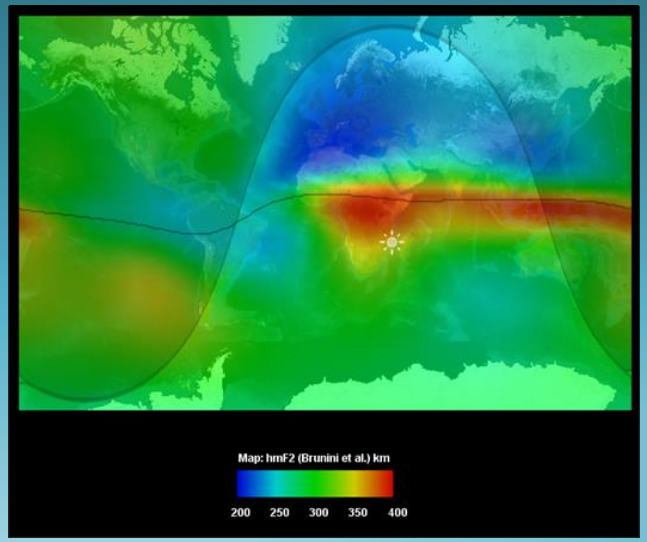
IRI-based Assimilation Concept for 2D maps

Global background model of hmF2



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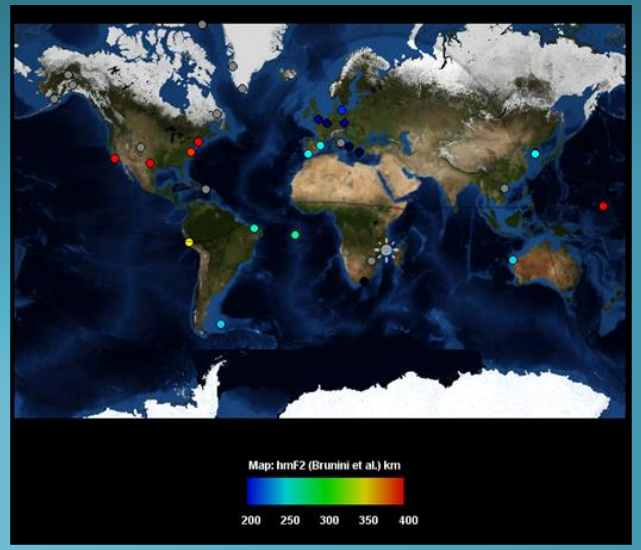
Ionosonde Network Real-Time hmF2



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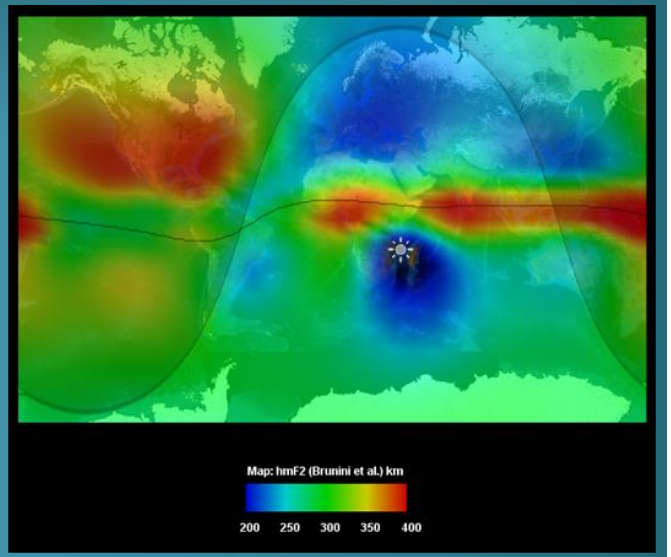
Global hmF2 Weather Model



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NECTAR is not quite a Kalman Filter

NECTAR

SLIDING 24-HOUR WINDOW

SENSORS SENSORS SENSORS

UPDATE 15 min UPDATE 15 min UPDATE

IRI IRI IRI

Kalman Filter's tough times caused by data noise

- GAIM and assimilation of foF2
- Testing of GPSII for HFGeo

IRI-based 1-DITL

24-hour 4DDA

One run = 24 hour fit

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IRTAM is a physics-informed model

(not a theoretical white box model)

- **A GRAY BOX approach**
  - IRI background is responsible for capturing underlying geophysics with solar, seasonal, and geomagnetic field dependencies
  - IRTAM merely ***adjusts*** IRI background 1-DITL
    - Computes anomaly coefficients Δ_{jm} to add to the original **13 x 76** C_{jm}
- **Principles of IRTAM:**
  - **Treat ionosphere in terms of its "disturbed" oscillations about IRI**
    - Extrapolate in space when possible
    - If one GIRO site sees a wavy anomaly in time, expand this to outside the site
  - **Represent 24-hour observations** faithfully
    - Certain smoothing effects are possible
      - Sean S. validation project confirms this smoothing effect
      - But smoothness in time and space is a valuable property
        - » Assimilation of non-cooperative transmitter signals (GPSII by NWRA)
          - 2-year HFGeo Phase III project to mate GPSII and IRTAM
  - **Gradually return to the background** over no-sensor regions

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Principles of IRTAM: NECTAR Technique

NECTAR

- **NECTAR algorithm, original version:**
  - At each sensor site k, use 24-hour history of *deviations* from IRI, $D_k(t)$
  - Expand $D_k(t)$ into j diurnal harmonics Δ_{kj}
    - Use the same 6th order Fourier series as in IRI
    - Rumor: coefficients of the 8th order Fourier expansion are somewhere
  - Interpolate-Extrapolate Δ_{kj} to global 2D, individually for each j
    - Important! NECTAR works with harmonics of the anomaly timeline at each site
  - Expand to Jones-Gallett spatial basis m
  - Add 998 resulting corrections Δ_{jm} to 998 original IRI coefficients
- **NECTAR with a Twist**
  - A linear-trend term added to IRTAM's diurnal harmonics
    - Original IRI wraps around midnight into the same value as 24 hours ago
    - Linear trend
    - Total 1024 coefficient

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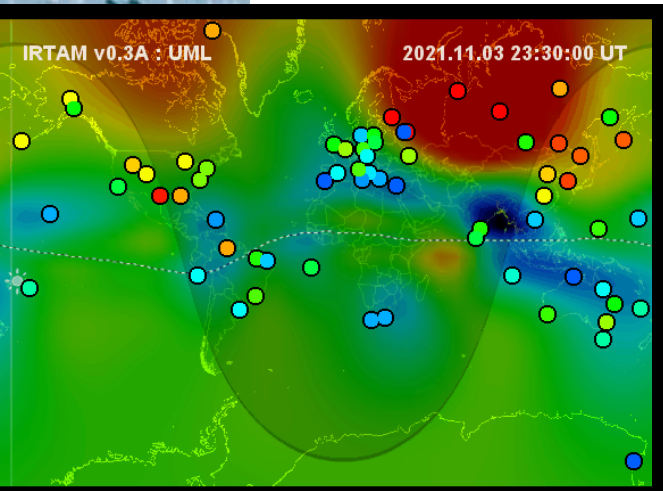
November 4, 2021 Storm, Kp ~ G3..G5

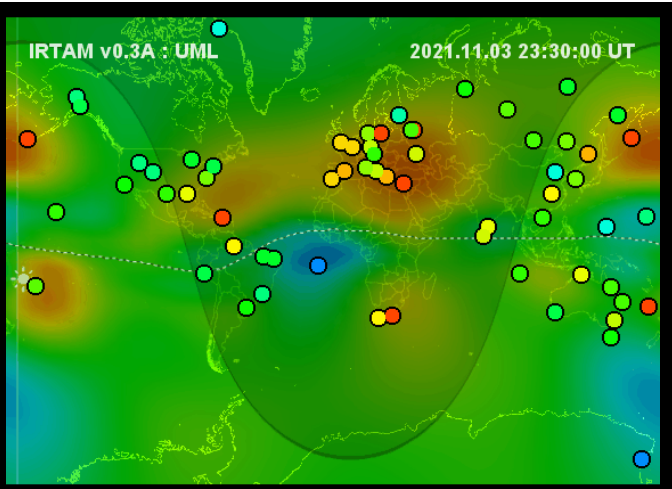
GIRO ionosondes only, IRTAM 3D assimilative model

NOT A SIMULATION!

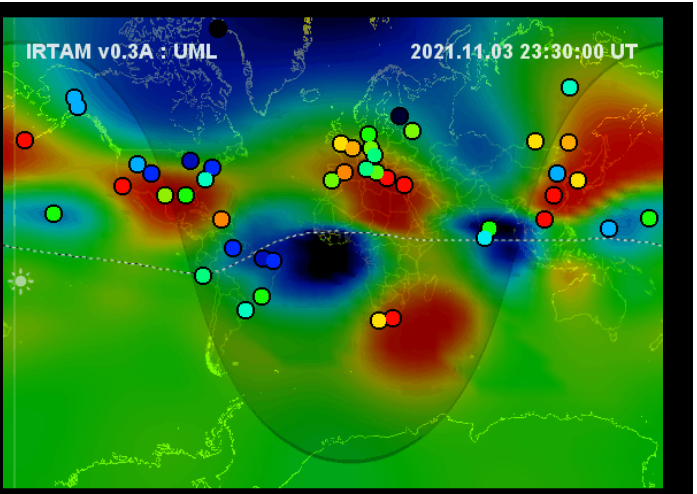
Would not it be nice to have these at CCMC!



Δ foF2



Δ hmF2



Δ B0

"Anomaly map" = Percent Deviation from Quiet Conditions

Gambit eXplorer

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COOPERATION OF IRI, GIRO AND GNSS

Data Fusion of VTEC and NmF2

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Anomaly maps by IGS and GIRO networks

St. Patrick storm
March 17, 2015 23:15

Madrigal 12763 pp

2015.03.17 23:15:00 UT

SED plume!

Super-fountain!

Gambit eXplorer
giro.uml.edu/GAMBIT

vTEC data courtesy MIT Haystack Madrigal Repository

Sites: NmF2 (GIRO-IRI)/IRI %

-75 -37.5 0 37.5 75

Map: Delta-VTEC, %

-75 -38 0 38 75

ΔNmF2 @ 60 GIRO sites

ΔvTEC @ 6342 GNSS sites

Viewing IRTAM computations

- **GAMBIT Explorer**

- **Download from https://giro.uml.edu/GAMBIT**

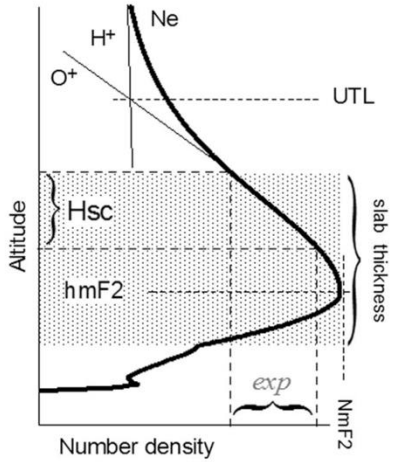
Cooperation of GNSS and GIRO

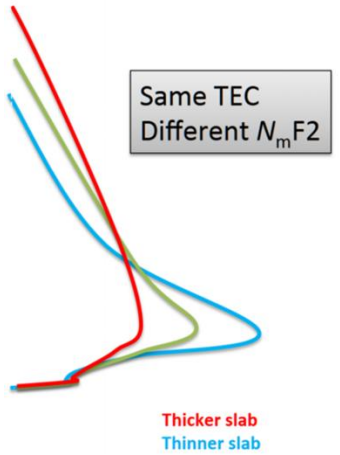
OTHERS:

- 2D: use observed ΔvTEC to derive corrections to NmF2 over no-coverage areas
  - T. Gulyaeva et al.
  - A. Pignalberi et al.
- Assimilate GIRO and GNSS data simultaneously in a 3D model
  - 6000 vs 60 problem
    - GIRO input is insignificant
  - GPSII: weighted assimilation
    - Fridman *et al.*, NWRA/HFGeo

OUR APPROACH:

- DATA FUSION PROJECT
  - Combine NmF2 and vTEC measurements to reason about slab thickness τ





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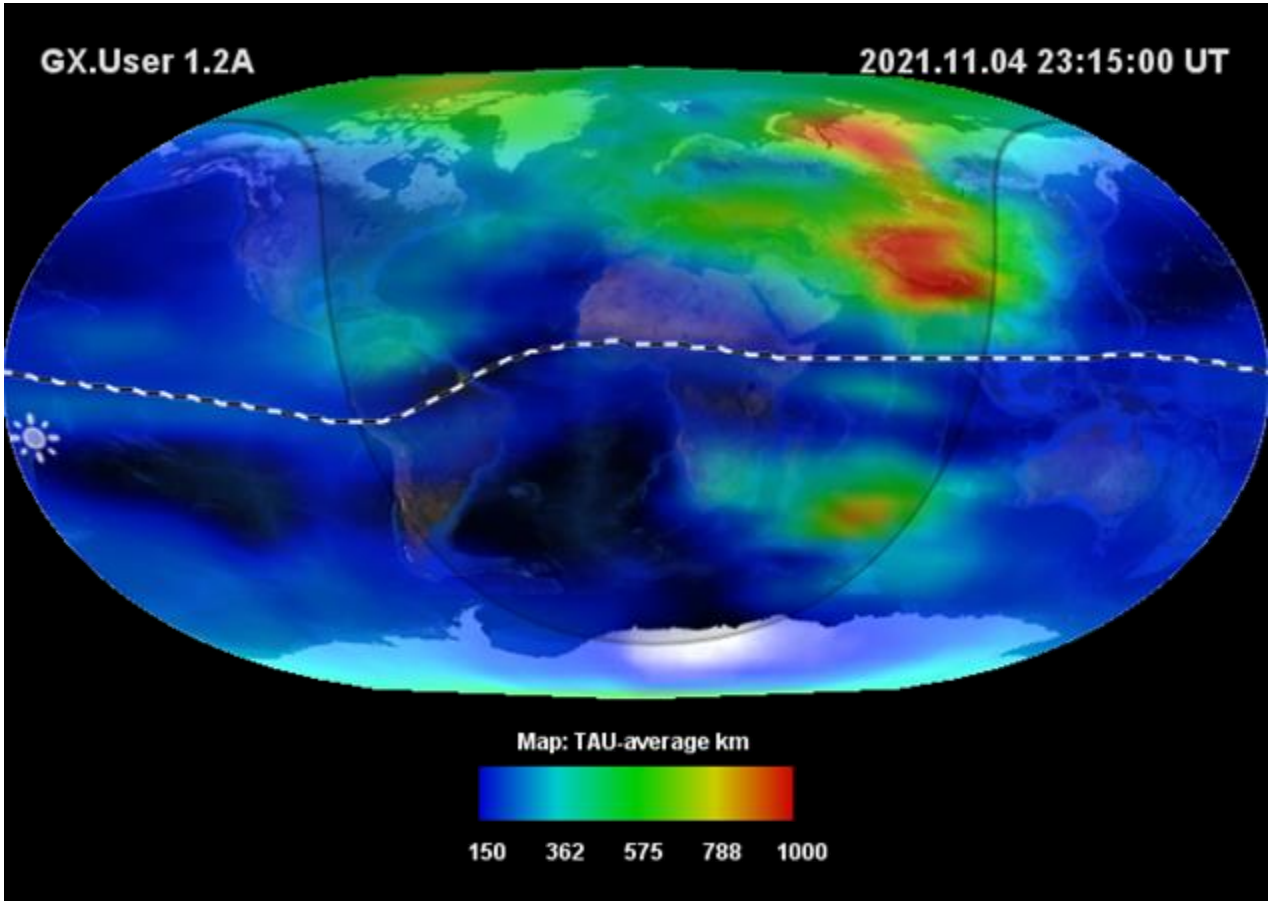
Slab Thickness Climatology



NmF2: IRI foF2 model (climate)
VTEC: IGS 30-day median VTEC

[Fron *et al*., 2020]

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BACKUP SLIDES

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IRTAM Open Problems and Path Forward

- **Diplomatic issues with data providers**
- **Need to complete fusion with near-real-time global VTEC maps (GIMs)**
  - Work with IGS Coordination Center at UWM Olztyn
- **ELO (Elastic Linear Optimizatioin): capability**
  - Assimilate sensor data from moving platforms such as COSMIC/SPIRE
  - 4DDA technique to analyze 24-hour history of RO data
  - Similar *Model Morphing* approach as in NECTAR
- **h_mF2 dilemma in IRTAM: did not fare well in comparisons to COSMIC h_mF2 data**
  - Possibly related to the IRTAM using IRI-2000 background climate specification of h_mF2
  - Upgrade IRTAM to Shubin *et al*. background model of h_mF2 from IRI 2020
  - Rerun comparisons to COSMIC/RO h_mF2
- **Optimize attenuation trajectories**
- **Improve MUF(3000) weather mapping algorithm by involving ionosonde data**
- **Increase expansion orders in IRTAM?**
  - Capture finer detail
  - Improve "underestimation" problem due to smoothing artifacts
- **Assimilate VTEC in IRTAM?**
- **Ingest WDC/SPIDR ionosonde archives into DIDBase, rerun IRTAM?**